BRIEF PHYSICS SURVEY WITH CMS IN YEAR ONE

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The CMS detector is one of the two general purpose experiments that will study the collisions produced by the Large Hadron Collider (LHC). The LHC is supposed to start its operation in 2007 at an instantaneous luminosity of $2{\times}10^{33}$ cm^{-2}s^{-1} , which may well result in an integrated luminosity of 10 fb^{-1} after the first year of running. The corresponding physics reach of CMS is exemplified with the study of a few standard model channels (weak boson and top quark production) and with the searches for Higgs bosons.

1 Introduction

The Large Hadron Collider (LHC) is designed to produce pp collisions at a nominal luminosity of 10^{34} cm^{-2}s^{-1} . With the foreseen startup luminosity of 2×10^{33} cm^{-2}s^{-1}, the LHC is expected to deliver an integrated luminosity of about 10 fb^{-1} in the first year of running. The corresponding physics reach of the CMS experiment [1] is briefly surveyed in this document, both with Standard Model (SM) studies (Section 2) and searches for Higgs bosons within the SM (Section 3) and its minimal supersymmetric extension, the MSSM (Section 4). The PYTHIA Monte Carlo generator [2] was normally used to generate the primary interactions for all production processes. The detector simulation and reconstruction packages CMSIM [3] and ORCA [4] were used to accurately reproduce the response of the detector for benchmark channels. However, to allow large event samples to be produced and statistically robust studies to be performed the fast simulation package CMSJET [5], parameterised to reproduce the results of the complete simulation for particle identification, b-tagging, missing energy resolution and jet reconstruction, was often preferred. In both cases the online selection chain, which consists of the Level-1 trigger and the High-Level Trigger (HLT), was simulated [6].

The physics reach after the first year of running is closely related to the level of understanding of the detector behaviour. In particular, the accuracy that will be achieved in the alignment

of the inner tracker and muon detectors and the calibration of the calorimeters is expected to play a crucial role. All the results presented in this document assume a perfectly aligned and calibrated detector.

2 Standard model physics

Standard model particles, particularly W and Z bosons and t quarks, will be copiously produced at the LHC, and easily detectable at startup through their leptonic decays (electrons and muons). At a centre-of-mass energy of 14 TeV in pp collisions the cross sections in final states with leptons, $\mathrm{W} \to \ell\nu_\ell$, $\mathrm{Z} \to \ell^+\ell^-$ and $\mathrm{t\bar{t}} \to \mathrm{W^+bW^-\bar{b}} \to \ell\nu_\ell + \mathrm{X}$, amount to approximately 20, 2 and 0.13 nb per lepton generation, respectively, which correspond to event production rates of 40, 4 and 0.26 Hz at startup luminosity. Table 1 shows the corresponding event yields of the muon channels expected with $10\,\mathrm{fb}^{-1}$ in the detector acceptance when the Level-1 trigger and the HLT transverse momentum thresholds are applied (17 and $9\,\mathrm{GeV}/c$ at the HLT for single and dimuon events, with at least one muon isolated). In one year, between ten and hundred million

	σ (nb)	Acc. (%)	Eff. (%)	Yield for 10 fb^{-1}
$\mathrm{W} \to \mu\nu_\mu$	19.6	50	69	7×10^7
$\mathrm{Z} \to \mu^+\mu^-$	1.84	71	92	1.1×10^7
$t\bar{t} \to \mathrm{W^+bW^-\bar{b}} \to \mu\nu_\mu + \mathrm{X}$	0.126	86	72	7.8×10^5

Table 1: Cross section, geometric acceptance, online selection efficiency and yield for some representative SM decay modes with at least one muon in the final state. The geometric acceptance is defined as the percentage of events with at least one muon at generation in the muon system nominal coverage: $|\eta| < 2.1$. The Level-1 and the HLT selection is tuned for the initial luminosity of 2×10^{33} cm^{-2}s^{-1} expected at the LHC.

Z and W events are therefore expected with at least one muon in the detector acceptance. These events (and those with electrons in the final state) are foreseen to be primarily used for tracker and muon system alignment and calorimeter calibration purposes. A survey of the methods foreseen for each sub-detector can be found in [6] and in the references therein. The Z events will be used to set the lepton energy and momentum scale, which is expected to be one of the major sources of uncertainty on several precise measurements of the SM parameters like the W mass. It is foreseen that with the first 10 fb^{-1} the error on the W mass will be already of the order of 30 MeV [7], which is better than what achieved at LEP [8] and comparable to the ultimate expectations of the Run II at the Tevatron [9]. A full review on the SM physics to be done at the LHC can be found in [7]. Finally, a detailed understanding of the W, Z and t quark pairs events is of importance in the quest for new physics as they often constitute the major background sources to, *e.g.*, Higgs boson or Supersymmetry searches.

3 The search for the SM Higgs boson

All existing direct searches and precision measurements performed at LEP and SLD are compatible with the existence of a SM-like Higgs boson of mass between 114.4 [10] and 211 GeV/c^2 [8] at 95% C.L. A heavier Higgs boson, however, can be consistent with the precision electroweak measurements in models more general than the minimal standard model [11]. The CMS experiment was designed to extend the mass range in which a discovery could take place all the way up to about $1\,\mathrm{TeV}/c^2$. The expected statistical significance of such a discovery with an integrated luminosity of 10 fb^{-1} is displayed in Fig. 1 [12] for the most relevant signals observable with the CMS detector and for their combination as a function of the Higgs boson mass (m_H). In this figure, the signal and background cross sections were computed at leading order only (the inclusion of k factors would change the expected significance by $k_\mathrm{signal}/\sqrt{k_\mathrm{background}}$).

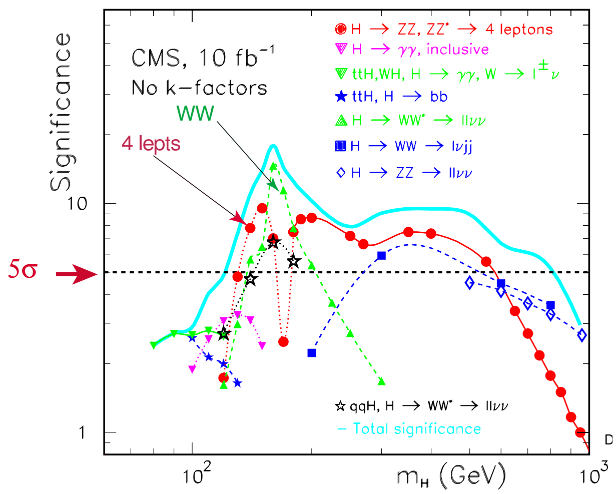

Figure 1: Expected statistical significance ($S/\sqrt{B}$) with 10 fb^{-1} for the SM Higgs boson as a function of m_{H}. Leading order cross sections are used for all processes.

- As can be seen in Fig. 1, the spectacular signature from the Higgs boson decay into four charged leptons, $\mathrm{H} \to \mathrm{ZZ} \to \ell^+\ell^-\ell^+\ell^-$, allows the mass range from 130 to 600 GeV/c^2 to be covered [13], with a gap around the WW threshold.

- To cover the gap caused by the drop of the ZZ branching fraction in this region, the decay $\mathrm{H} \to \mathrm{W}^+\mathrm{W}^- \to \ell^+\nu_\ell\ell^-\bar{\nu}_\ell$ is best suited for an early discovery [14]. The most important sources of background to this channel are $\mathrm{t\bar{t}}$, WW and Wt production. It has been demonstrated that jet veto in the central rapidity region allows the $\mathrm{t\bar{t}}$ and Wt backgrounds to be suppressed while WW spin correlation effects are an effective tool against the WW continuum production.

- Finally, Higgs boson masses below 130 GeV/c^2 need the contribution from the $\gamma\gamma$, $\mathrm{b\bar{b}}$ and $\tau^+\tau^-$ (not shown in Fig. 1) decay channels, in addition to all of the above. These decay channels are expected to be particularly difficult because of large backgrounds. The difficulty of the task is illustrated in Fig. 2, which shows the $\gamma\gamma$ invariant mass spectrum in the presence of a SM Higgs boson with mass 120 GeV/c^2 [15]. Next to leading order cross sections are used for both signal and background. Events are selected requiring in the HLT two isolated photons having transverse momenta greater than 25 and 40 GeV/c. Clearly, this channel relies on an excellent electromagnetic calorimeter calibration.

Despite the lower cross section with respect to the gluon fusion production mechanism ($\mathrm{gg} \to \mathrm{H}$), signal events produced in the weak boson fusion channel ($\mathrm{qq} \to \mathrm{qqH}$) display the additional feature of two energetic jets in the forward and backward directions. In addition, the absence of colour exchange in the hard process leads to a low jet activity in the central rapidity region. These two features allow high rejection of the $\mathrm{t\bar{t}}$, single W and Z production accompanied by jets and QCD multi jet backgrounds. Very interesting results have been obtained for the decay channels of a low mass Higgs boson produced via the weak boson fusion process: $\gamma\gamma$ [16], $\mathrm{b\bar{b}}$ [17], $\tau^+\tau^-$ [18] and also $\mathrm{W}^+\mathrm{W}^- \to \ell^+\nu_\ell\ell^-\bar{\nu}_\ell$ [19].

4 Higgs boson searches in the MSSM

In the MSSM, at least two Higgs doublets are needed, in contrast to the minimal standard model in which only one Higgs doublet is necessary. After three degrees of freedom are used to

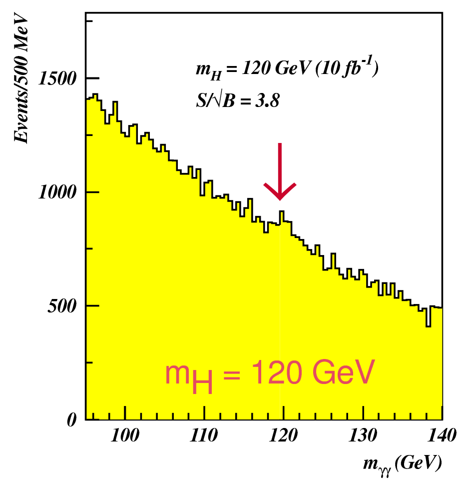

Figure 2: $\mathrm{H} \to \gamma\gamma$ ($m_\mathrm{H} = 120$ GeV$/c^2$) signal on the top of the background with 10 fb^{-1}.

give masses to the W and Z bosons, five physical states remain: two charged Higgs bosons $\mathrm{H}^\pm$ and three neutral Higgs bosons h, H and A (h and H are scalars while A is pseudoscalar). The lighter scalar Higgs boson h is expected to have a mass smaller than 130 GeV$/c^2$ and to behave like the SM Higgs boson over most of the $\tan\beta$-m_A parameter space, where $\tan\beta$ is the ratio of the vacuum expectation values of the two Higgs doublets. Its discovery, therefore, needs the full statistics of the first year and a well aligned and calibrated detector. The heavier neutral Higgs bosons H and A, however, benefit from an enhancement of their coupling to b quarks and τ's by $\tan\beta$. Furthermore, the large branching fraction at high $\tan\beta$ of $\mathrm{A/H} \to \tau^+\tau^-$ and $\mathrm{H}^\pm \to \tau\nu_\tau$ makes these final states best suited for discovery over a significant portion of the $\tan\beta$-m_A parameter space. Therefore, good b- and τ-tagging capabilities, to be performed also online, are crucial for this searches. Several τ- and b-tagging algorithms have been developed in CMS, as reported in [6] and in the references therein. The algorithms that have been tested in the HLT selection use the information from the calorimeters, which define cones of interest centred around the reconstructed jets, and from the innermost layers of the tracker detector, which allow the primary vertex and the parameters of the tracks belonging to the jets to be determined. The identification of a τ jet is based on the reconstruction of an isolated collimated jet. The left plot in Fig. 3 shows the performance of a b-tagging algorithm [6] that relies on the measurement of the track impact parameter. The version of the algorithm, indicated as "HLT" in the plot, has proved to be sufficiently robust and fast for use in the CMS HLT selection. The reconstructed $\tau^+\tau^-$ invariant mass distribution [20] for $m_\mathrm{A} = 200$ GeV$/c^2$ and $\tan\beta = 40$ in the fully leptonic final state of the heavy neutral Higgs bosons ($\tau^+\tau^- \to \ell^+\nu_\ell\ell^-\bar{\nu}_\ell$) after background rejection with b-tagging is shown in the right plot of Fig. 3. A significant excess over the background is clearly visible with 10 fb^{-1}. Hadronic τ decays increase the search sensitivity to larger values of m_A as can be seen in Fig. 4, which shows the coverage of the parameter space obtainable with CMS and 10 fb^{-1} for the maximal stop mixing scenario and by considering just the channels involving the heavy Higgs bosons.

5 Conclusions

Examples of the physics reach of the CMS detector with an integrated luminosity of 10 fb^{-1} have been briefly summarised. Within a year about one million t quark pairs and over 100 million W and Z bosons are expected to be produced with an electron or muon in the final state, which will also allow the detector to be accurately aligned and calibrated. Less than 10

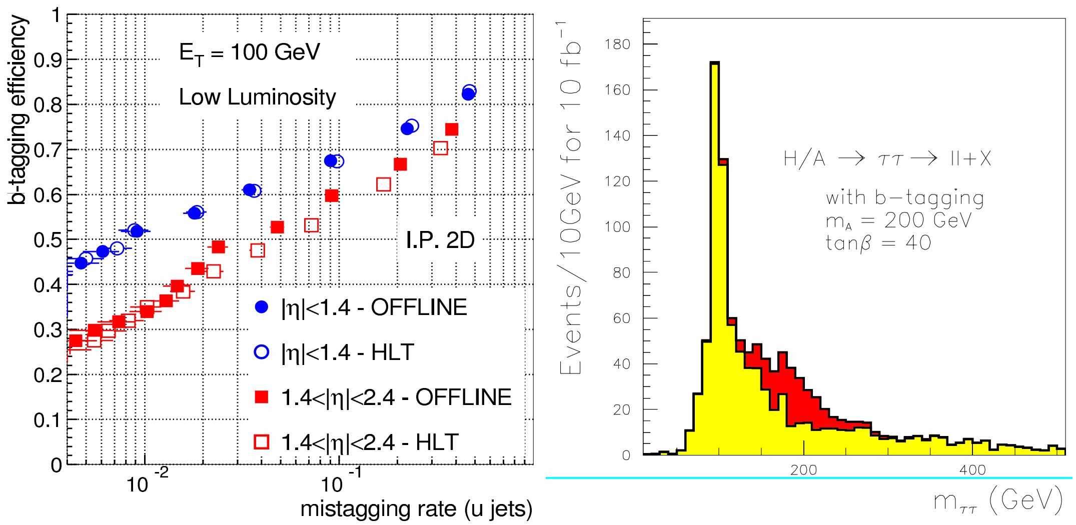

Figure 3: Left: Efficiency of the b-tagging versus mistagging rate for jets with transverse energy of 100 GeV. Right: Reconstructed mass distribution of the $\mathrm{H/A} \to \tau^+\tau^- \to \ell^+\nu_\ell\ell^-\bar{\nu}_\ell$ signal and background with 10 fb^{-1}.

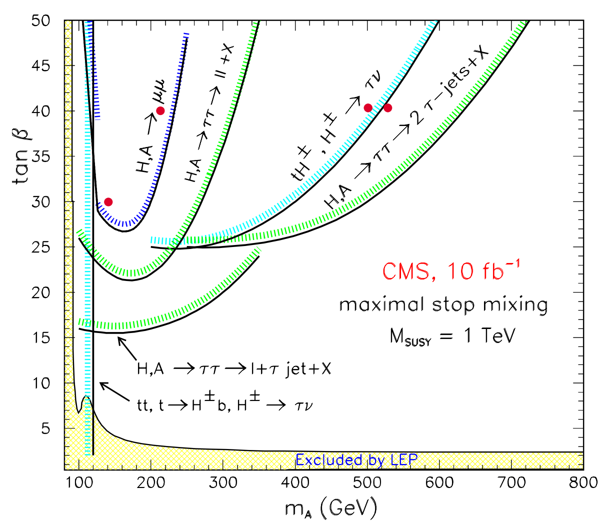

Figure 4: Expected 5σ discovery reach with 10 fb^{-1} for the MSSM heavy Higgs bosons in CMS in the maximal mixing scenario as a function of m_A and $\tan\beta$.

fb^{-1} is needed for a 5σ discovery of the SM Higgs boson over the whole mass range from 130 to 700 GeV/c^2. For smaller mass an entire year and a well aligned and calibrated detector are needed. A significant fraction of the MSSM parameter space is expected to be covered with the first 10 fb^{-1} by looking for the heavy neutral Higgs bosons H and A decays in the $\tau^+\tau^-$ final state.

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